First Application of 66-kV Outdoor Terminations with Composite Hollow Insulators for XLPE Cable

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ABSTRACT Composite hollow insulators have a number of advantages over porcelain insulators, including lighter weight, better anti-pollution and anti-explosion properties, and easier construction. They are therefore being considered for use with outdoor terminations installed on towers for branching.

Tokyo Electric Power and Furukawa Electric have jointly developed a 66-kV outdoor termination with composite hollow insulators, and have used it on Tokyo Electric Power's Oihama line--the first such application in Japan.

This paper outlines the performance specified for the 66-kV termination, together with development tests and evaluation results, and the specifications of equipment supplied to the Oihama Line.

1. INTRODUCTION

Because of their long track record, porcelain insulators are the mainstay of outdoor electrical insulation applications. But over the past 20 years on-going improvements in the characteristics of silicone rubber and other polymer materials have led to increased use of composite insulators, which are lighter in weight, mechanically stronger and better in anti-pollution properties, as interphase spacers and strain insulators. More recently hollow type composite insulators have also been used for bushings in gas-insulated equipment.

The main structural elements of a composite hollow insulator is an FRP tube having high mechanical strength, covered with a silicone rubber housing or shed having superior weather-resistance and electrical insulation properties, and with metal fittings strongly fastened at both ends.

Composite hollow insulators are superior to porcelain insulators in several respects, including lighter weight, better anti-pollution and anti-explosion properties, and easier assembly. Active consideration is therefore being given to their introduction when installing outdoor cable terminations on towers.

This paper outlines the process of developing an outdoor termination with composite hollow insulators, describing artificial pollution tests using samples, development specifications, development and evaluation test results, and the specifications of the products installed.

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2. COMPOSITE HOLLOW INSULATORS

Composite hollow insulators--also known a silicone rubber or polymer insulators--are usually made of an epoxy-type FRP tube manufactured by a filament winding technique, covered with a silicone rubber housing or shed and with metal fittings fastened at both ends. The FRP imparts mechanical strength, while the silicone rubber provides weather resistance and external insulation performance. Filament-wound FRP is particularly strong against inner pressure, and the silicone rubber owes its anti-pollution properties to its hydrophobicity and low molecular weight (LMW) effects. As would be expected from the constituent elements used, unit mass is low--only about 20-30% that of porcelain insulators.

In recent years composite hollow insulators have been increasingly used in Europe and the U.S. as bushings for gas circuit breakers.

3. ARTIFICIAL POLLUTION TESTS ON SILICONE RUBBER

Tokyo Electric Power and Furukawa Electric have carried out a joint program of research with a view to using these composite hollow insulators in outdoor terminations [1]. One of the primary advantages of these insulators is their resistance to pollution. The present situation is as follows:

- There are few examples of their use in working lines, so field test data is inadequate;
- The artificial pollution test methodology now in use was developed to evaluate porcelain insulators, so there is much room to doubt that evaluations are

made under conditions that reflect the special characteristics of composite hollow insulators and the silicone rubber housings.

In our development testing, we have conducted artificial pollution tests using sample tubes to control the adherence of contaminants while utilizing the hydrophobicity of silicone rubber, and have found that [2]:

- As in the case of porcelain insulators, outer diameter has an effect on withstand voltage characteristics under pollution;
- The withstand voltage under pollution decreases with a rise in the equivalent salt deposit density (ESDD) on the surface of the sample, but when ESDD exceeds 1.0 mg/cm^2 no further decrease takes place.

We therefore came to the conclusion that for composite hollow insulators with an average outer diameter of 260 mm (hereinafter referred to as 66-kV rated), a creepage distance of more than 33.25 mm/kV would be ample even if ESDD exceeded 1.0 mg/cm^2.

For 66-kV composite hollow insulators for outdoor terminations, we may calculate the creepage distance required using 69 kV, the target pollution withstand voltage, by

33.25 mm/kV x 69 kV = 2295 mm

4. DESIGNING A TERMINATION WITH COMPOSITE HOLLOW INSULATOR

The design specifications for the composite hollow insulator termination were arrived at by analogy, to maintain compatibility with existing porcelain insulators.

4.1 Electrical Design

The required levels of initial electrical performance and long-term loading were determined in conformance with JEC-3408 [3], and with Electrical Standards A-263 [4], which are based on it.

4.2 Mechanical Design

The mechanical properties of the insulators under bending are determined on the basis of the levels of wind pressure, inner pressure, seismic force and short-circuit electromagnetic force anticipated during operation. But since the composite hollow insulator is lighter in weight than porcelain, the load with respect seismic force resulting from the weight of the insulator itself is reduced.

By selecting the appropriate inner FRP for the composite hollow insulator at the design stage, it is possible to establish mechanical strength that is broadly in accordance with the required specifications.

Mechanical strength for the composite hollow insulator is set so that the maximum designed cantilever bending force and the maximum designed inner pressure satisfy, respectively, the requirements for maximum mechanical load (MML) and maximum service pressure (MSP) as set forth in IEC-61462 [5].

4.3 Anti-Pollution Design

With respect to anti-pollution design--that is to say the surface creepage distance of the composite hollow insulator--using the results from tube sample tests described above we may set the lower limit for creepage distance using data for an ESDD of 1.0 mg/cm^2, no matter how high the ESDD of the region may be. By this line of reasoning creepage in regions with ESDD of over 0.06 mg/cm^2 (equivalent to heavy or very heavy pollution) is shorter by 20% or more compared to porcelain insulators.

The present situation, however, is that:

- There is no clear correlation between tests on sample tubes and long-term anti-pollution performance in the field;
- Most examples of creepage distance design for equipment used in composite hollow insulators in the past have been established based on creepage distance designs for porcelain insulators.

Accordingly the following procedures for creepage distance design were established, erring on the side of safety:

- The creepage distance for 66-kV rated terminations with composite hollow insulators was established according to "Anti-Pollution Design for Substation Equipment" [6], which is the basic design standard for porcelain insulators;
- Notwithstanding the above, to take advantage of the possibility of reduced creepage distance suggested by the sample tube tests, the track record resulting from actual operation should be taken into account to allow future reductions in creepage distance of up to 5% from the porcelain design described above.

5. EVALUATION TESTS

Table 1 shows the evaluation tests, which were carried out using a prototype outdoor termination designed for medium pollution (ESDD of less than 0.6 mg/cm^2).

5.1 Withstand Voltage and Long-Term Voltage Tests

As can be seen from Tables 2 and 3, both the initial withstand voltage tests and the long-term (6-month) voltage tests were satisfactory.

The long-term voltage tests were carried out over a 6-month period at a test site in a seaboard industrial area on an outdoor termination located about 10 m from the shoreline. The voltage applied was 1.44 times 66-kV cable voltage to ground. Snowfalls also occurred during the tests

Table 1 Specifications of terminations subjected to electrical performance tests

	XLPE cable specifications			
	Conductor size		Insulation thickness	
66 kV	2000 mm^2		10 mm	
	Composite hollow insulator specifications			
	Length (mm)	ID (mm)	Creepage distance (mm)	Weight (kg)
Prototype for 66 kV	1100	198	2390	17

but on completion of the tests no degradation of the housing was observed. After the long-term voltage test, the terminations also passed a test to evaluate residual performance, under the conditions shown in Table 4.

5.2 Outdoor Exposure Tests

Outdoor exposure tests of the bare composite hollow insulator were carried out using insulators having the same specifications as those subjected to the 6-month voltage test. The applied voltage was 53 kV. The test was carried out to check for water penetration to the interior of the composite hollow insulator, and to evaluate the condition of the housing.

The inside of the composite hollow insulator was filled with silicone oil and the oil was periodically sampled and analyzed, and although an increase in moisture content was observed, there was a tendency to saturate [1], and it was confirmed that the level was not such that its electrical performance was affected.

The hydrophobicity of the housing was evaluated by the STRI method, and a drop from HC1 to HC2 was not observed after the elapse of more than 3 years.

Photo 1 Long-term aging testing of 66-kV termination with composite hollow insulator

Table 2 Results of withstand voltage tests for terminations

Test items \ Product tested	Prototype for 66 kV	
DC	-167 kV for 1 hr	Good
AC	130 kV for 1 hr	Good
Lightning impulse	-485 kV for 3 times	Good

Table 3 Result of long-term aging tests for terminations

Test items \ Product tested	Prototype termination for 66 kV	
Test voltage	55 kV	
Conditions	Heat cycling	
	Cable conductor temperature	90°C x 150 cycles 105°C x 30 cycles
	Power cycle	8 hr on; 16 hr off
Test period	6 month	
Results	Good	

Based on the results of these evaluation tests, it was determined that the 66-kV outdoor termination with composite hollow insulators was fully suited for use in working lines.

6. INITIAL APPLICATION TO THE OIHAMA LINE

The No. 1 tower of Tokyo Electric Power's Oihama Line is located in Chuo Ward in the city of Chiba, in an area subject to heavy pollution (ESDD of 0.12 mg/cm^2, a Class D area according to Tokyo Electric Power's system of classification). Cables with a conductor size of 800 mm^2 were led from the tower by outdoor terminations. Normally B-1054 porcelain insulators would be used in Class D areas, but the location on the tower makes washing and other

Table 4 Withstand voltage tests after long-term aging test

Test items \ Product tested	Prototype termination for 66 kV (after long-term test)	
AC	75 kV for 10 min	Good
Lightning impulse	-485 kV for 3 times	Good

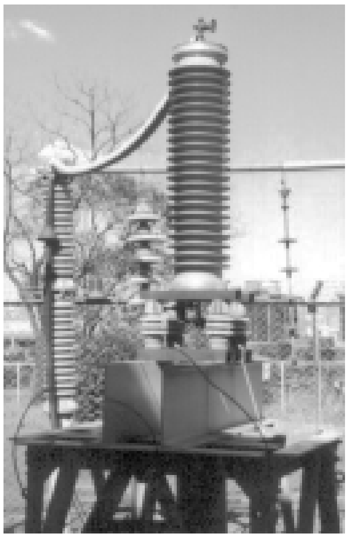
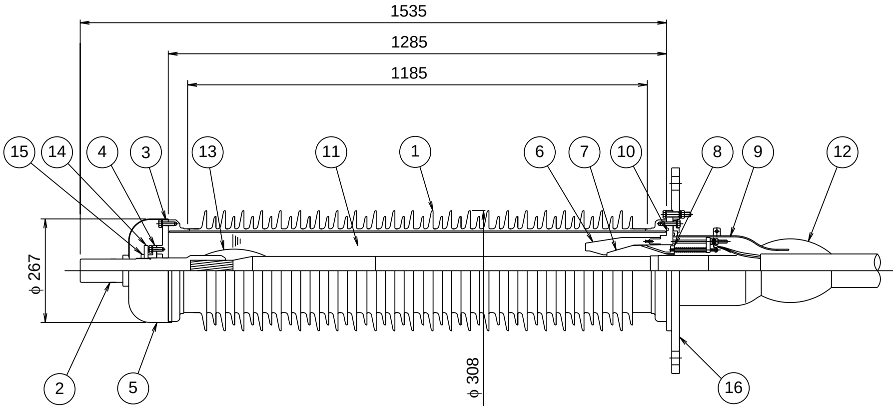


Photo 2 Outdoor long-term exposure test set-up

Photo 3 Hydrophobicity classification (HC1 to HC2) on insulator surface



No.	
16	Mounting flange
15	Lock nut
14	Conductor fixing metal
13	Sealing tape
12	Water-proofing tape
11	Insulation compound
10	O-ring
9	Cable protecting metal
8	Compressing device
7	Pre-molded stress-relief cone
6	Epoxy insulator
5	Upper cover
4	Clamping metal
3	Upper metal
2	Conductor rod
1	Composite hollow insulator

Figure 1 Termination with composite hollow insulator for very heavy pollution

Table 5 Comparison of specifications of 66-kV rated insulators for very heavy pollution

Type of insulator	Composite	Porcelain
Length (mm)	1285	1725
Creepage distance (mm)	4150	4080
Weight (bare) (kg)	24	145
Estimated weight of termination (kg)	170	260
Type designation	CHI-66V1	B-1454

maintenance difficult so that B-1454 porcelain insulators, designed for areas of very heavy pollution (Class E) were installed.

Taking the opportunity offered by re-stringing with 1600-mm^2 conductors to increase capacity, it was decided to use terminations with composite hollow insulators in an effort to compensate for the increased load on the arms of the tower from the increased mass of the cables.

While the existing terminations using the B-1454 porcelain insulators weighed approximately 260 kg, the use of terminations with composite hollow insulators (designated type CHI-66V1) achieved a weight reduction down to about 170 kg. The housing of the CHI-66V1 was configured with alternating large and small sheds, achieving an overall length even shorter than the B-1054 porcelain insulator for heavy pollution duty, while maintaining a creepage distance equivalent to very heavy pollution duty.

Installation of the 66-kV terminations with composite hollow insulators was completed in April, 2000 and they went into commercial service that June.

7. CONCLUSION

Composite hollow insulators have many outstanding qualities, and to render them applicable to outdoor terminations a series of tests of anti-pollution performance were carried out on the silicone rubber used as the housing. Guidelines for application of composite hollow insulators to 66-kV outdoor terminations were also established, and a prototype was used to confirm electrical performance, both initial and after 6 months aging. It was also confirmed that penetration of moisture to the insulator had no effect on termination performance.

Photo 4 No. 1 tower of 66-kV Oihama Line, bearing outdoor terminations with composite hollow insulators

Based on these results, 66-kV terminations with composite hollow insulators were installed in Tokyo Electric Power's Oihama Line, the first such installation in Japan.

We are currently studying the application of this technology to 154-kV terminations. Terminations with composite hollow insulators offer the advantages of lighter weight and better anti-pollution performance, and it is hoped that they will be applied more widely, to simplify the structure of foundation frame and other ancillary equipment and to reduce maintenance work.

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